

Research Article

A New Early Warning Evaluation Method and Decision Mechanism for Urban Significant Emergency in Uncertain Environment

¹Qian-Sheng Zhang and ²Yi-Rong Huang

¹Department of Informatics, Guangdong University of Foreign Studies, Guangzhou, 510420, China

²SunYat-sen Business School, Sun Yat-sen University, Guangzhou, 510275, China

Abstract: This study presents a new early warning evaluating method and decision mechanism for urban emergency in which the risk factors are easily assessed by fuzzy numbers. By using the fuzzy preference relation matrix and the extended fuzzy AHP, the relative weight of each risk factor can be estimated. Then we evaluate the total fuzzy risk value by aggregating the severity of loss of risk factor and the relative weight of risk factor. According to the similarity between the fuzzy comprehensive risk value and the pre-established risk grade, the early warning grade of the urban significant emergency can be determined for urgent emergency decision-making.

Keywords: Risk evaluation, similarity measure, urban emergency, warning grade

INTRODUCTION

With the development and expansion of city, the frequency and strength of significant emergencies are increasing in many cities. So, urban significant emergency index analysis and early warning become very important research issues in emergency management. As is well known, the urban emergency inevitably affects many aspects of urban including urban economy recession, safety of environment and property and health condition. In the past decades, Zhang (2008) proposed the methods of index selecting and weighting for emergency. He and Lu (2010), Gao (2010), Zhao (2009), Zhou and Zhang (2006) and Sun (2007) have proposed some urgent decision making approaches for urban significant emergency. Also some early warning management methods for urban incidents have been introduced in He and Li (2012), Ye (2007), Zhi *et al.* (2009), Yang and Ding (2009), Lang (2011), Wang (2005), Ma and Wang (2006) and Wen and Bian (2006). However, most of the existing early warning mechanisms and decision methods can only deal with the urban emergency under precise condition. In fact, due to the increasing complexity of the socio-economic environment and the lack of knowledge about the problem domain, most of the real-world problems, such as urban emergency decision analysis and emergency warning degree evaluation, are involved variety of uncertainty like fuzzy number (Deng *et al.*, 2004) and fuzzy linguistic value (Rodriguez *et al.*, 2012). Especially, in the warning degree evaluation process of urban significant emergency it will inevitably involve

some fuzzy factors, including the serious economy depression, the wicked environment destroy, the improper emergency broadcasting, the enormous casualties and the critical traffic jam, as well as the inadequate emergency rescue facilities. Also, the values of above risk factors are easily expressed by fuzzy linguistic terms. Moreover, the unexpected and uncontrolled uncertain risks easily incur the urban significant emergency. So, in order to decrease the possibility of urban significant emergency, there is much need to analyze and control the risk of urban significant emergency. Also, it is a necessitous task for urban government department decision-maker to adopt the corresponding strategy to reduce the occurrence of significant emergency in urban zone according to the evaluated fuzzy comprehensive risk value.

Recently, many researchers studied the risk analysis of emergency (Liu and Yuan, 2006; Wang and Lin, 2009; Xiao, 2012; Ye and She, 2011), but the fuzzy risk factor was not considered. Although (Zhong and Xie, 2011) employed fuzzy entropy and comprehensive judgment method to calculate the occurring probability of risk, it has some drawbacks since it is based on traditional Shannon entropy. Li (2007) discussed the fuzzy comprehensive risk judgment of HR outsourcing, but the method is unable to determine the accurate risk grade. In fact, most of the existing fuzzy risk computing methods can not effectively cope with the risk evaluating and warning degree determining involved fuzzy risk factors. Thus, in this study we aim to propose a new fuzzy risk computing and warning degree evaluation approach for

urban emergency in uncertain environment. As we are aware, the warning grade of urban emergency is influenced by the severity of risk factor and the relative weight of risk factor. To obtain the relative importance of each fuzzy risk factor, we will develop an extended fuzzy AHP method in this study.

PRELIMINARIES

Fuzzy set (FS) introduced by Zadeh is a useful generalization of the ordinary set, which has been proved to be more suitable way for dealing with vagueness and uncertainty. Particularly, information entropy (Kosko, 1986), similarity measure and distance measure of FSs play very important roles in the application fields like pattern recognition (Li and Cheng, 2002), risk analysis and decision-making (Chen and Chen, 2007).

Definition 1: A fuzzy set $\tilde{a} = (a_1, a_2, a_3)$ in a universe of discourse X in R is called a triangular fuzzy number if its membership function can be expressed as the following form:

$$f_{\tilde{a}}(x) = \begin{cases} 0, & x \leq a_1 \text{ or } x > a_3; \\ f_{\tilde{a}}^L(x) = \frac{x-a_1}{a_2-a_1}, & a_1 < x \leq a_2; \\ f_{\tilde{a}}^U(x) = \frac{a_3-x}{a_3-a_2}, & a_2 < x \leq a_3. \end{cases}$$

Definition 2: Let $\tilde{a} = (a_1, a_2, a_3)$, $\tilde{b} = (b_1, b_2, b_3)$ be two triangular fuzzy numbers, some basic operations between them are given as follows:

$$\tilde{a} + \tilde{b} = (a_1 + b_1, a_2 + b_2, a_3 + b_3) \tag{1}$$

$$\tilde{a} \otimes \tilde{b} = (a_1, a_2, a_3) \otimes (b_1, b_2, b_3) = (l, m, u)$$

Where $l = \min(a_1 b_1, a_1 b_3, a_3 b_3)$, $l = \min(a_1 b_1, a_1 b_3, a_3 b_3, a_3 b_3)$, $m = a_2 b_2$, $u = \max(a_1 b_1, a_1 b_3, a_3 b_1, a_3 b_3)$.

Remark 1: If $(a_1, a_2, a_3) a_1 a_2 a_3 b_1 b_2 b_3 > 0$, and $k > 0, w > 0$, then:

$$\tilde{a} \otimes \tilde{b} = (a_1, a_2, a_3) \otimes (b_1, b_2, b_3) \tag{2}$$

$$(a_1 b_1, a_2 b_2, a_3 b_3)$$

$$1/\tilde{b} = 1/(b_1, b_2, b_3) = (\frac{1}{b_3}, \frac{1}{b_2}, \frac{1}{b_1})$$

$$\tilde{a}^k = (a_1^k, a_2^k, a_3^k)$$

$$w\tilde{a} = (wa_1, wa_2, wa_3)$$

Definition 3: The similarity measure between any two triangular fuzzy number $\tilde{a} = (a_1, a_2, a_3)$ and $\tilde{b} = (b_1, b_2, b_3)$ is defined as:

$$S(\tilde{a}, \tilde{b}) = \frac{1}{1 + |p(\tilde{a}) - p(\tilde{b})|} \tag{3}$$

where, $p(\tilde{a}) = (a_1 + 4a_2 + a_3)/6$, $p(\tilde{b}) = (b_1 + 4b_2 + b_3)/6$ are the graded mean integration representations of \tilde{a} and \tilde{b} .

Definition 4: Let $C = \{c_1, c_2, \dots, c_n\}$ be the early warning index set of urban emergency and $(g_{ij})_{n \times n}$ be the pair-wise comparison fuzzy preference matrix, where g_{ij} represents the fuzzy preference degree of index c_i over index c_j , $g_{ji} = 1/g_{ij}$. The fuzzy weight of each warning index can be defined by:

$$w_i = \frac{(\otimes_{j=1}^n g_{ij})^{1/n}}{\sum_{i=1}^n (\otimes_{j=1}^n g_{ij})^{1/n}} \tag{4}$$

EARLY WARNING EVALUATION AND DECISION FOR URBAN EMERGENCY

As we know, the urban significant emergency will possibly face to many kinds of risk factors with different probabilities. Especially in the uncertain emergency management environment, the accurate value of risk factor is difficult to measure, but by means of fuzzy linguistic term, we can conveniently represent the relative weight and the severity of loss of each risk factor. Through fuzzy risk analysis method, we can correctly estimate the risk grade of urban significant emergency. Generally, by questionnaire survey and statistical analysis from some field experts and emergency managers we can easily get some important risk factors that incur urban significant emergency, including the economy risk, the environment risk, the humanity risk and the traffic jam risk, public health risk, as well as the emergency facility risk, etc. Suppose the set of all risk factors of urban significant emergency is denoted by U . Generally, the risk factor is fuzzy concept, for example, serious economic recession, severe environment pollution, wicked emergency broadcasting, bad public health, incomplete emergency facility and so on. As we are aware, the accurate values of the severity of loss and the relative importance degree of each fuzzy risk factor are difficult to measure in uncertain setting, but easily assessed by fuzzy language terms, like $R = \{\text{Critical, Serious, Medium, Weak, Neglectful}\}$ and $W = \{\text{Extremely strong importance, Very strong importance, Strong importance, Moderate importance, Just Equal importance, Equal importance}\}$.

In order to simplify assessing the importance degree and severity of loss of the every risk factor of urban significant emergency, some unified sets of linguistic terms are predetermined as in Tables 1-2.

Table 1: Linguistic terms for comparing the importance degree of two warning indexes

Intensity of importance	Definition of Grade	Fuzzy numbers
9	Extremely strong importance	(7, 9, 9)
7	Very strong importance	(5, 7, 9)
5	Strong importance	(3, 5, 7)
3	Moderate importance	(1, 3, 5)
2	Just Equal importance	(1, 1, 3)
1	Equal importance	(1, 1, 1)

Table 2: Linguistic terms for rating the severity of loss of the risk factor in urban emergency

Linguistic terms	Fuzzy numbers
Critical	(0.9, 1.0, 1.0)
Serious	(0.6, 0.7, 0.8)
Medium	(0.4, 0.5, 0.6)
Weak	(0.3, 0.4, 0.5)
Neglectful	(0.0, 0.1, 0.2)

Table 3: 5-Linguistic terms for rating the warning grade of urban significant emergency

Linguistic terms	Fuzzy numbers
Extremely high (EH)	(0.9, 1, 1)
Very high (VH)	(0.7, 0.8, 0.9)
Fairly high (FH)	(0.5, 0.6, 0.8)
Medium (M)	(0.2, 0.4, 0.5)
Low (L)	(0.1, 0.2, 0.3)

Table 4: Decision mechanism for corresponding early warning grade of urban emergency

Early warning grade	Emergency decision mechanism
G ₁ (Extremely High marked by Red alarm)	Mobilize ambulance and transport urgent needs
G ₂ (Very High marked by Orange alarm)	Coordinate emergency management among different municipal zones and districts
G ₃ (Fairly High marked by Yellow alarm)	Monitor the safety hazard in some important urban areas and estimate the public interest losses of intimidate
G ₄ (Medium marked by Blue alarm)	Examine the procedures and facilities for coping with emergency and notify citizens to take some necessary safety measures
G ₅ (Low marked by Green alarm)	Keep education and training in safety and get ready for dealing with possible emergency

In order to determine the risk warning grade of urban emergency and provide early warning in time, we set five different risk grades of urban significant emergency by fuzzy linguistic terms as in Table 3.

Here, we denote all the five risk grades by the set $G = \{G_1(EH), G_2(VH), G_3(FH), G_4(M), G_5(L)\}$ (VH)} Based on the previous risk analysis, here we give the fuzzy comprehensive risk evaluation process for urban significant emergency involved fuzzy risk evaluation value in uncertain environment.

Step 1: Let U be the set of all fuzzy risk factors $\{u_1, u_2, \dots, u_n\}$ of urban significant emergency and by pair-wise comparison between warning indexes we construct the fuzzy comparison preference matrix $\tilde{D} = (\tilde{r}_{ij})_{n \times n}$, where $\tilde{r}_{ij} = (l_{ij}, m_{rij}, u_{rij})$ is the fuzzy preference

degree of risk factor u_i over risk factor u_j , which can be given by the knowledge and experience of field experts.

Step 2: By using formula (4), we can compute the relative weight vector of all the risk factors in uncertain urban emergency:

$$w_i = \frac{(\otimes_{j=1}^n g_{ij})^{1/n}}{\sum_{i=1}^n (\otimes_{j=1}^n g_{ij})^{1/n}}, i = 1, 2, \dots, n \quad (5)$$

Step 3: Calculate the fuzzy comprehensive risk value according to the above relative weight and the severity of loss of each risk factor in urban significant emergency by the following formula:

$$R = \sum_{i=1}^n (w_i \otimes R_i) / \sum_{i=1}^n w_i \quad (6)$$

where, R_i is the severity of loss of the risk factor u_i .

Step 4: Calculate the similarity measure $S(R, G_j)$ between the fuzzy comprehensive risk value R and each pre-established risk grade G_j , where G_j is the j th risk grade in the pre-established risk grade set $G = G_1 (EH), G_2 (VH), G_3 (FH), G_4 (M), G_5 (L) \}$.

Step 5: Determine the risk warning grade of the unexpected urban significant emergency. By means of the similarity degree calculated, we can determine the risk warning grade of the uncertain urban significant emergency. If $k = \arg \max_j \{S(R, G_j) | 1 \leq j \leq 5\}$, then the unexpected urban emergency should belong to the given risk grade G_k .

Step 6: According to the estimated early warning grade, we can design the decision mechanism and adopt the corresponding emergency response or strategy to reduce the risk of urban emergency as displayed in the following Table 4.

ILLUSTRATIVE EXAMPLE

Recently, emergency managers and field experts usually tend to employ fuzzy values to evaluate the uncertain urban emergency with respect to various warning indexes. In this section, we give a numeric example to illustrate the application of the proposed fuzzy AHP and fuzzy early warning degree evaluation approach in uncertain urban significant emergency.

Example 1: Now suppose the urban government try to design an emergency decision mechanism and carry out some emergency rescue measures, it requires the

Table 5: Pair-wise comparison fuzzy preference matrix of the risk factors in urban significant emergency

	u1	u2	u3	u4
u1	(1, 1, 1)	(2/3, 1, 3/2)	(5/2, 3, 7/2)	(7/2, 4, 9/2)
u2	(2/3, 1, 3/2)	(1, 1, 1)	(2/7, 1/3, 2/5)	(2/3, 1, 3/2)
u3	(2/7, 1/3, 2/5)	(5/2, 3, 7/2)	(1, 1, 1)	(5/2, 3, 7/2)
u4	(2/9, 1/4, 2/7)	(2/3, 1, 3/2)	(2/7, 1/3, 2/5)	(1, 1, 1)

emergency management monitor all the uncertain index information of possible urban emergency and evaluate the comprehensive risk value of urban emergency and estimate the warning degree. Assume the set of risk factors $U = \{u_1$ (serious environment disruption and bad public health condition), u_2 (disloyal disaster report), u_3 (incomplete emergency facility), u_4 (severe traffic jam)} must be taken into account for the urban significant emergency. And the fuzzy preference degree is evaluated by experts. From the related emergency management experts, assume we know that the severities of loss of the above four risk factors of urban significant emergency are serious, medium, weak and critical, respectively.

Our main task is to determine the early warning grade of the urban significant emergency involved fuzzy linguistic value. That is to decide which risk grade, out of the five grades G_1, G_2, \dots, G_5 , the unexpected urban emergency should belong to. In what follows we employ the fuzzy extended AHP method to calculate the relative weight of each risk factor and then compute the total risk value of urban significant emergency and then help the related urban emergency management department adopt the corresponding decision mechanism to decrease the comprehensive risk of urban emergency.

First, we regard Table 5 as the fuzzy preference matrix $\tilde{D} = (\tilde{r}_{ij})_{4 \times 4}$ of risk factors, where \tilde{r}_{ij} denotes the fuzzy preference degree of risk factor u_i over u_j .

By using the extended fuzzy AHP and formulae (1), (2), (4), we can compute the relative weight vector of risk factors in urban emergency by the formula:

$$w_i = \frac{(\otimes_{j=1}^4 g_{ij})^{1/4}}{\sum_{i=1}^4 (\otimes_{j=1}^4 g_{ij})^{1/4}}, \quad i = 1, 2, \dots, 4$$

Thus, the relative weight vector of all the risk factors of urban significant emergency are obtained as:

$$\begin{aligned} W_1 &= (0.2927, 0.416, 0.5863) \\ W_2 &= (0.1124, 0.1698, 0.259) \\ W_3 &= (0.2177, 0.2941, 0.3956) \\ W_4 &= (0.0854, 0.1201, 0.1711) \end{aligned}$$

Next, according to the given severity of loss of each risk factor:

$$\begin{aligned} & (R_1, R_2, R_3, R_4) \\ &= \{\text{Serious, Medium, Weak, Critical}\} \end{aligned}$$

$$= \{(0.6, 0.7, 0.8), (0.4, 0.5, 0.6), (0.3, 0.4, 0.5), (0.9, 1, 1)\}$$

From the previous formulae (5), (6), we calculate the fuzzy comprehensive risk value as:

$$\begin{aligned} R &= \sum_{i=1}^4 w_i R_i / \sum_{i=1}^4 w_i \\ &= (0.1756, 0.2912, 0.469) + (0.045, 0.0849, 0.1554) + \\ &\quad (0.0653, 0.1176, 0.1978) + (0.0769, 0.1201, \\ &\quad 0.1711) \\ &= (0.3628, 0.6138, 0.9933) \end{aligned}$$

Then, according to the similarity formula (3) between fuzzy numbers, we calculate the similarity measures between the calculated fuzzy risk value and each given risk grade in $G = G_1$ (EH), G_2 (VH), G_3 (FH), G_4 (M), G_5 (L) } as follows:

$$\begin{aligned} S(R, G_1) &= 0.7418, S(R, G_2) = 0.8585 \\ S(R, G_3) &= 0.9818, S(R, G_4) = 0.7988 \\ S(R, G_5) &= 0.6968 \end{aligned}$$

Since $S(R, G_3) > S(R, G_2) > S(R, G_5)$, i.e., $3 = \arg \max_j \{S(R, G_j) / G_j \in G\}$, the comprehensive risk of urban significant emergency should belong to G_3 grade and the risk of this urban significant emergency may be "Fairly high" and marked by orange alarm. That is to say, the unexpected urban significant emergency will undertake some risk of grade G_3 . The related urban emergency management department will raise the corresponding warning and take emergency mechanism and strategy to monitor the safety hazard and estimate the public interest losses of intimidate, even coordinate all kinds of urgent management facilities among different municipal zones and districts to decrease the risk of the unexpected urban emergency before implementing some emergency response.

CONCLUSION

In this study, we propose an extended fuzzy AHP to calculate the relative weight of each risk factor, it is then used to compute the fuzzy comprehensive risk value of urban significant emergency. Finally, according to the similarity measure between the evaluated fuzzy comprehensive risk value and each given risk grade, we can assign the urban significant emergency to the proper warning grade, which can help the related urban emergency management department make the correct decision mechanism in accord with the early warning evaluation result.

ACKNOWLEDGMENT

This study is supported by the Humanities and Social Sciences Youth Foundation of Ministry of Education of China (Nos.12YJJCZH281, 11 YJJCZH

086, 10 YJC 790 104), the Guangzhou Social Science Planning Project "The study of early warning index selection and urgent decision mechanism for city significant emergency in uncertain environment" (No. 2012GJ31), the National Natural Science Foundation (Nos. 60974019, 61070061, 60964005), the Fundamental Research Funds for the Central Universities in China and the Guangdong Province High-level Talents Project.

REFERENCES

- Chen, S.J. and S.M. Chen, 2007. Fuzzy risk analysis based on the ranking of generalized trapezoidal fuzzy numbers. *Appl. Intell.*, 26: 1-11.
- Deng, Y., W.K. Shi, F. Du and Q. Liu, 2004. A new similarity measure of generalized fuzzy numbers and its application to pattern recognition. *Pattern Recogn. Lett.*, 25: 875-883
- Gao, J., 2010. Analysis on the coordinative governance of the urban sudden events. *J. Fujian Admin. Ins.*, 6: 29-32.
- He, L. and B.Y. Lu, 2010. Study on urban emergency aided decision model "1+1". *Sci. Technol. Manag. Res.*, 21: 216-219.
- He, Y.Q. and J. Li, 2012. Research on grading of emergency events and response measures based on traffic. *J. Catastrophol.*, 27(2): 105-108.
- Kosko, B., 1986. Fuzzy entropy and conditioning. *Info. Sci.*, 40(2): 165-174.
- Lang, P.J., 2011. The operation mechanism of modern city emergency prediction and early warning. *Urban Manag.*, 2: 21-24.
- Liu, J.K. and G.L. Yuan, 2006. The risk management investigation of critical emergency. *J. Coll. Railway Police*, 1: 35-39.
- Li, L., 2007. The risk analysis of HR epiboly based on the fuzzy integrated evaluation. *J. Zhongnan Univ. Eco. Law*, 4: 35-40.
- Li, D.F. and C.T. Cheng, 2002. New similarity measures of intuitionistic fuzzy sets and application to pattern recognitions. *Pattern Recog. Lett.*, 23: 221-225.
- Ma, Y., L. She and C. Wang, 2006. The construction and operation of domestic city traffic emergency early warning management system. *J. Wuhan Univ. Technol.*, 28(1): 67-70.
- Rodriguez, R.M., L. Martinez and F. Herrera, 2012. Hesitant fuzzy linguistic term sets for decision making. *IEEE T. Fuzzy Syst.*, 20(1): 109-119.
- Sun, Y.M., 2007. Research on construction of emergency response mechanism and platform for domestic urban incidents. *J. Chongqing Univ. Posts Tele.*, 19(1): 59-65.
- Tang, W.Q., 2008. Study on city emergency response pattern in China. *Chinese Admin.*, 3: 79-82.
- Wang, C., 2005. Study on early warning management model of society significant emergency. *J. Wuhan Univ. Technol.*, 18(1): 26-29.
- Wang P. and J.P. Lin, 2009. The evaluation system investigation of emergency in the main railroad. *Railway Comput. Appl.*, 18(9): 1-3.
- Wen, Z.Q. and X.R. Bian, 2006. The emergency management of city incidents: Challenge and strategy. *J. College of Disaster Prev. Tech.*, 8(2): 15-19.
- Xiao, K.H., 2012. The risk early warning model study of emergency in supply chain. *J. Henan Univ. Technol.*, 8(1): 54-57.
- Yang, L.Z. and J.D. Ding, 2009. Discussion on emergency management of city incidents. *Info. Sci.*, 27(3): 351-355.
- Ye, G.R., 2007. Early warning mechanism of the urban emergency: The connotation and system. *Contemp. Econ. Manag.*, 29(2): 69-72.
- Ye, J.Z. and L. She, 2011. Risk analysis and management of network emergency: A suggested framework. *Soft Sci.*, 25(12): 59-67.
- Zhang, W.P., 2008. Study on the index selecting and weight evaluation for emergency early warning. *J. Chinese People's Public Secur. Univ.*, 6: 80-89.
- Zhao, L.D., 2009. Theory study of city coordinative emergency decision generation. *J. Southeast Univ.*, 1: 49-55.
- Zhi, J.Y. Gan and F. Guo, 2009. Study on the application of transport system in dealing with city emergency. *Software Guide*, 8(11): 106-107.
- Zhong, R.Q. and Y.J. Xie, 2011. Application of fuzzy risk assessment and entropy coefficient in the software outsourcing. *Sci. Technol. Eng.*, 11: 2625-2628.
- Zhou, C. and Y. Zhang, 2006. The construction of urgent decision system of Chinese city emergency during the transitional Period. *J. Chongqing City Manag. Vocat. Coll.*, 6(4): 34-37.